Project ID: EEMS026

U.S. DEPARTMENT OF ENERGY

SMARTMOBILITY

Systems and Modeling for Accelerated Research in Transportation

Expanding Regional Simulations of CAVs to the National Level and Assessing Uncertainties

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2017 DOE Annual Merit Review and Peer Evaluation Meeting
JUNE 7, 2017

Overview

Timeline

Project start: 1 Jul 2015

Project end: 30 Sep 2018

Percent Complete: 40%

Barriers

- Large uncertainty in energy and GHG implications of connected and automated vehicles
- Lack of methods for aggregating case studies and for estimating future adoption potential

Budget

FY 2016: $450k

FY 2017: $216k (2B) + $296k (2C)

– 100% DOE

Partners

- Interactions / Collaborations
  - National Renewable Energy Laboratory
  - Oak Ridge National Laboratory
  - University of Illinois at Chicago
- Project lead: T. Stephens, Argonne

Objective

- Estimate potential changes in petroleum consumption and GHG emissions due to deployment of connected and automated vehicles (CAVs) at a national level
  - Develop CAV deployment scenarios
  - Define data gaps and analysis needs to direct in-depth case studies and analysis (performed under separate effort)
  - Develop methods to estimate potential CAVs technology adoption rates
  - Develop methods to aggregate results of case studies to the national level
  - Apply methods and deliver estimates of national level energy impacts of CAVs

http://its.dot.gov/cv_basics/cv_basics_benefits.htm

Relevance: Vehicle Technologies Office must consider the energy and emissions implications of connected and autonomous vehicles (CAVs)

- DOE EERE Vehicle Technologies Office (VTO) develops and deploys efficient and environmentally-friendly highway transportation technologies that will provide Americans with greater freedom of mobility and energy security, while reducing costs and impacts on the environment
- CAVs may disrupt patterns of travel patterns, vehicle use and ownership, and even vehicle design with large changes in energy consumption
- Proposed analysis of CAVs under VTO-funded SMART Mobility CAVs Pillar (see EEMS002) will provide estimated energy impacts at the local and regional levels
- The results (with other results as available) must be expanded to the national level

Key questions:

- ***What are the bounds on potential energy consumption implications of CAVs at the U.S. national level?***
- ***What are the key considerations for encouraging energy beneficial outcomes and for mitigating adverse energy outcomes?***

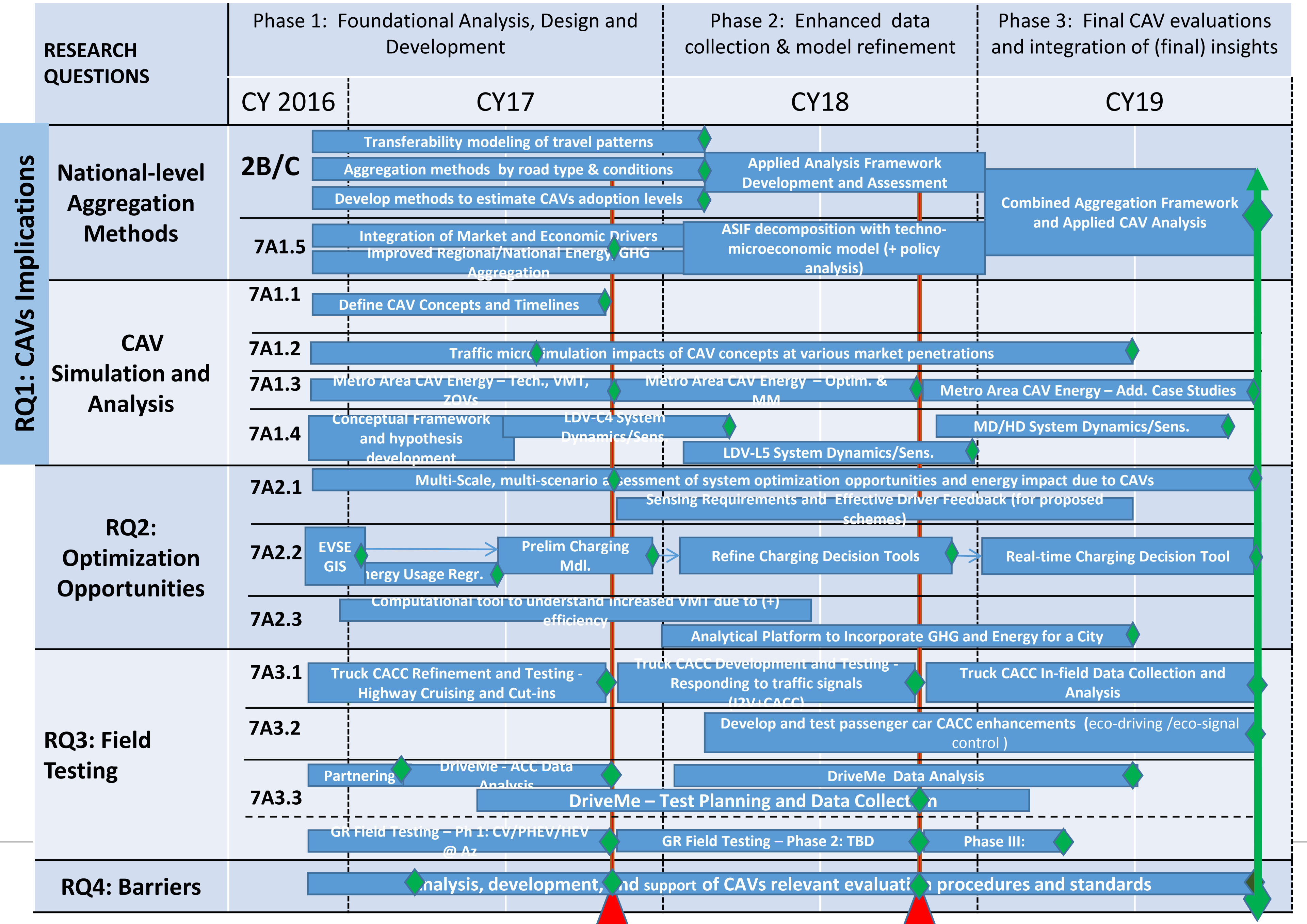
Challenges

- Drawing conclusions from current literature
  - Disparate scenarios and case studies differ in assumptions and methodologies
  - Results can't be combined or extrapolated to national level
- Estimating future adoption levels of various CAV technologies in different vehicle applications
- Taking results of simulations and analyses at a vehicle, local or regional level and expanding estimated changes in travel, fuel use and GHG emissions to the national level

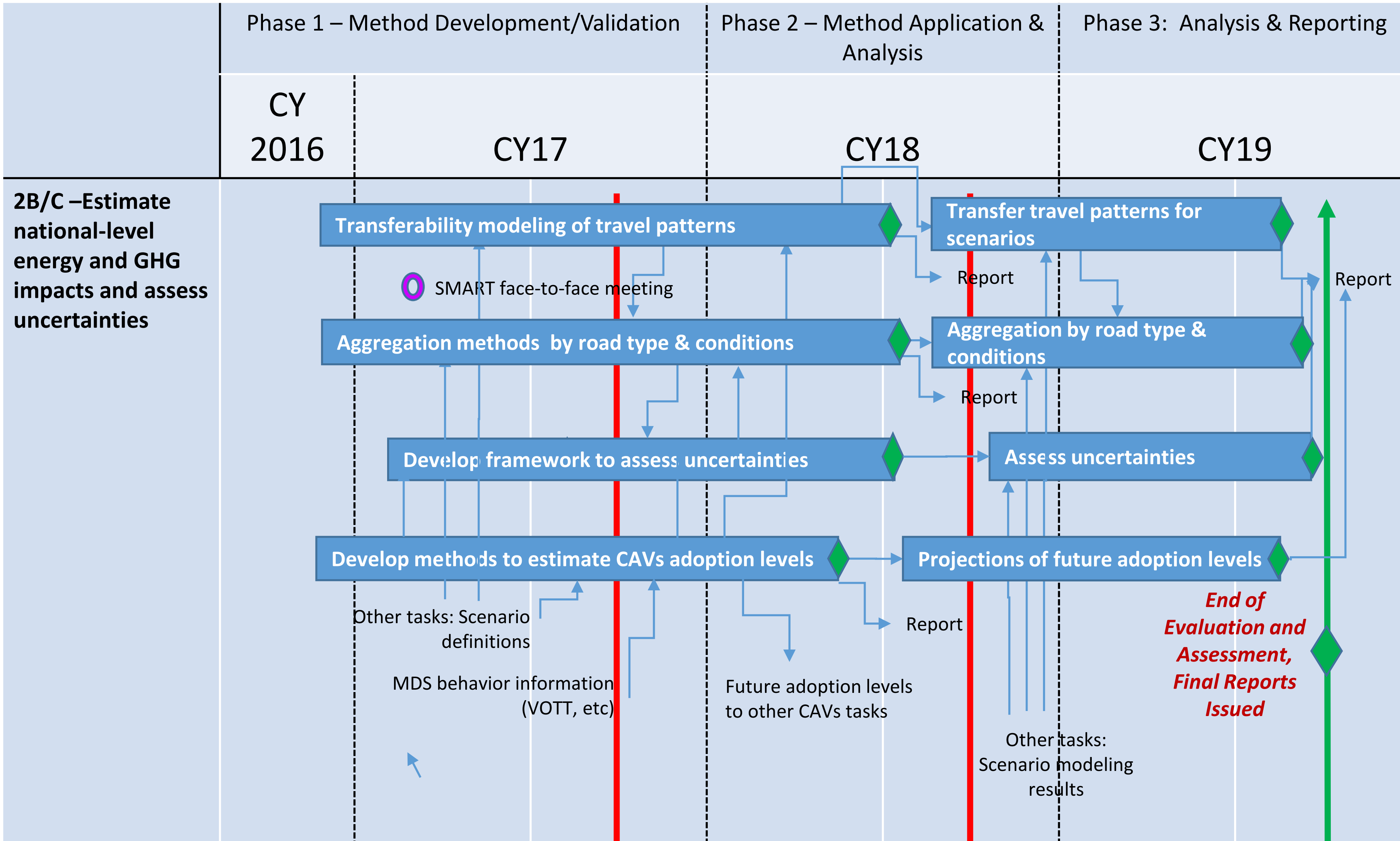
Milestones

Month/year	Description	Status
Dec 2016	Identify possible CAVs scenario/use cases	Complete
Dec 2016	Energy bounds report	Complete
Jun 2016	Establish framework for exploring uncertainty sensitivity	Complete
Sep 2016	Initial synthesis of scenarios and estimates of potential ranges of energy impacts at a national level for light-duty passenger travel	Complete
Dec 2016	Energy bounds report	Complete
Jun 2017	Report on CAVs national-level expansion methods identifying “expandable” use cases	In progress
Sep 2019	National-level energy impacts for multiple scenarios	

CAV Project RoadMap – Project Overview



CAV Subproject 2B Roadmap



Are there enough energy benefits to continue research/modeling? Are the right research questions/priorities being pursued? Leveraging partners successfully? Resolved project redundancies? Relevance to DOE mission clear?

Is there benefits shown to justify continuing? Have research questions been answered? Is there a potential path forward? What is it?

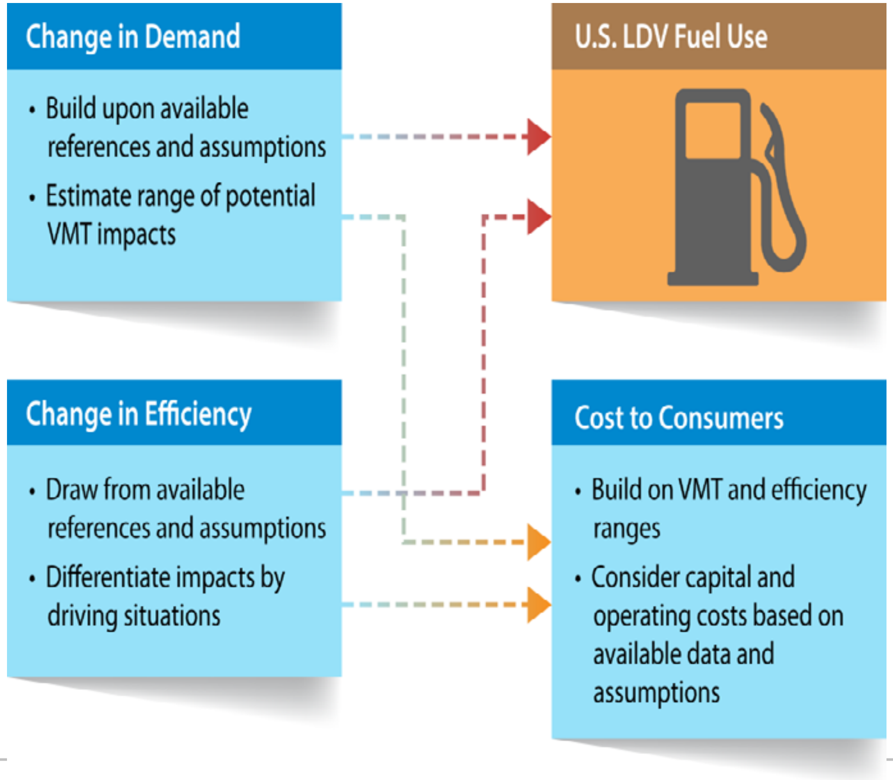
Were models validated? Did prototypes work? Did deployment increase? Was tech transfer successful?

What have we learned from this investment? How will the results push forward the SOP/SOA? How will the results put DOE in a thought leadership position? What happens next?

Approach: Initial literature review and assessment

- Objectives
  - Review relevant studies and assess what's known about potential energy and market implications of CAVs for passenger travel energy use
  - Identify key knowledge gaps/uncertainties

- Methodology
  - Estimate demand and efficiency impacts from 12 factors
  - Calculate upper and lower bounds for fuel consumption and consumer cost
  - Identify key uncertainties and directions for future research



Approach: Factors studied

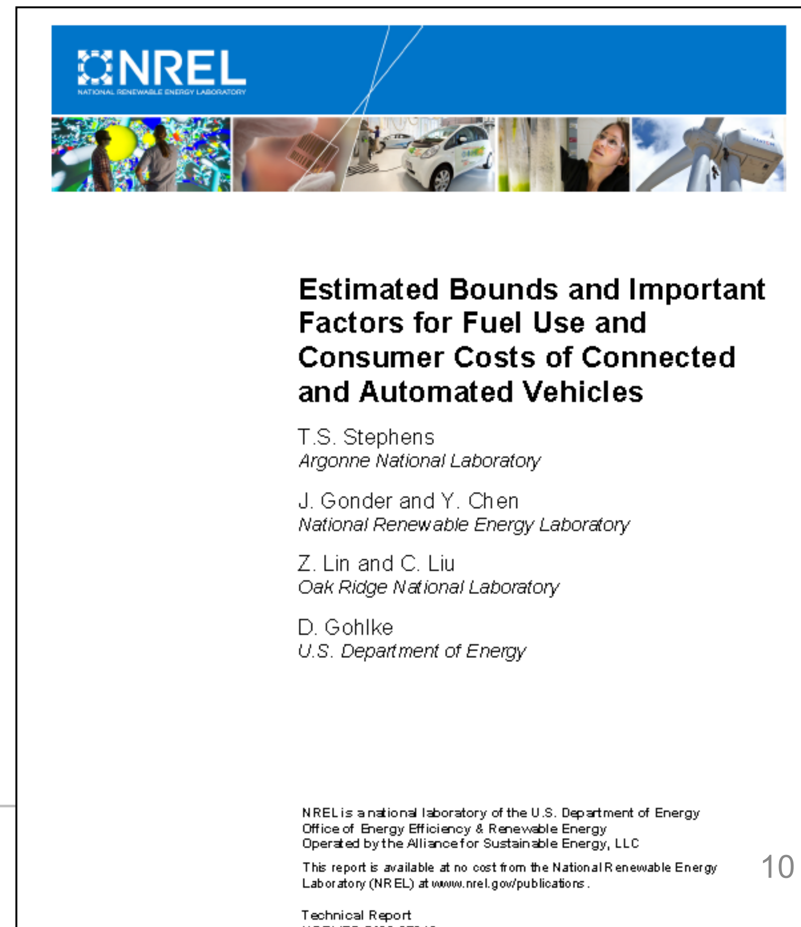
- **Demand**
  (Changes in VMT)
  (Changes in 'mobility')
  ↑ Easier Travel
  ↑ Underserved
  ↑ Empty Miles
  ↑ Mode Shift
  ↓ Hunting for Parking
  ↓ Ridesharing

- **Efficiency**
  (Changes in MPG)
  (Changes in 'operation')
  ↑ Vehicle Resizing
  ↑ Drive Smoothing
  ↑ Platooning
  ↑ Collision Avoid
  ↑ Intersection V2I
  ↓ Fast Travel

- **Also reviewed estimated costs**

Accomplishment:

Report: Stephens et al., (2016) Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles, http://www.nrel.gov/docs/fy17osti/67216.pdf


NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles

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Argonne National Laboratory

J. Gonder and Y. Chen
National Renewable Energy Laboratory

Z. Lin and C. Liu
Oak Ridge National Laboratory

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U.S. Department of Energy

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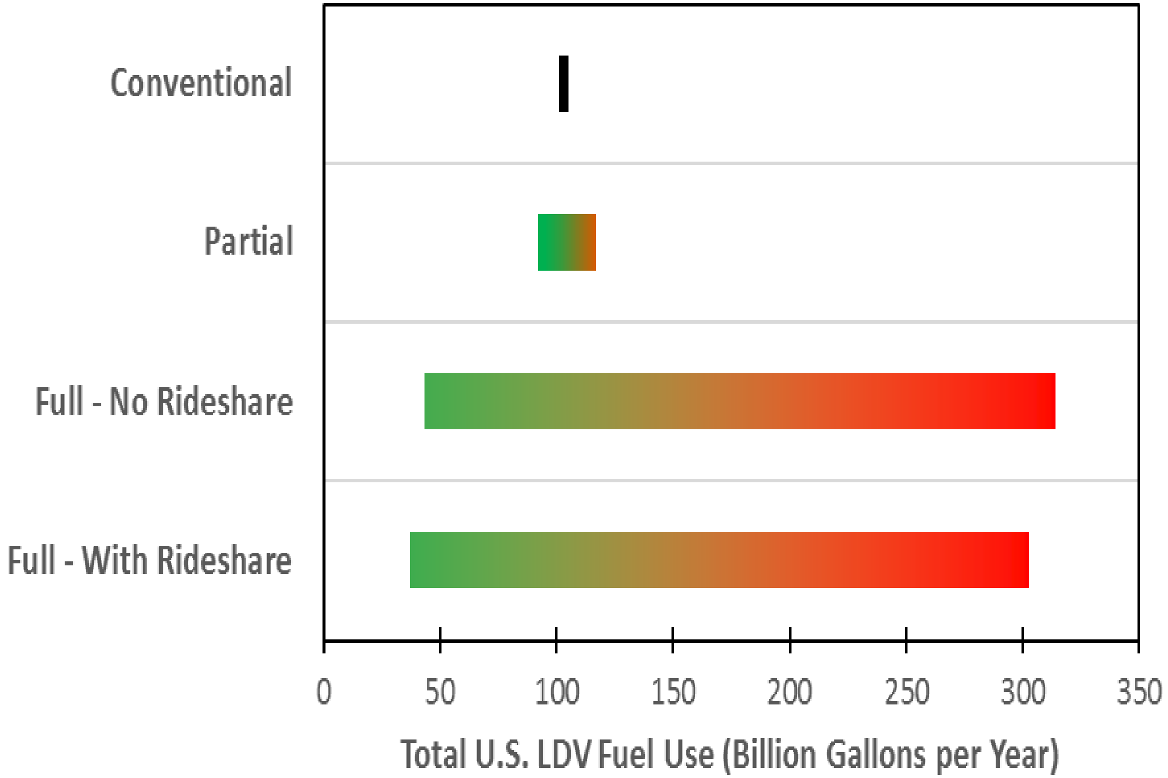
Technical Report

See VAN020 presentation

Accomplishment: Potential energy impacts of automation



Partial automation:
± 10–15%

Full automation:
– 60% / +200%

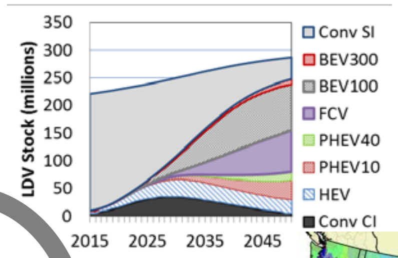
Ride-sharing:
Reduction of
up to 12%

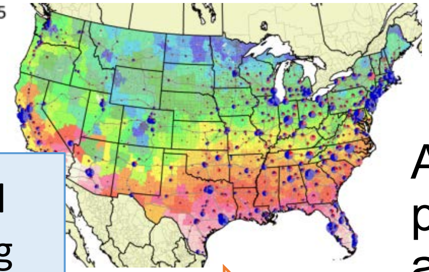
- Assuming no fuel switching nor major vehicle improvements

Results from: Stephens et al., Estimated Bounds and Important Factors for Fuel Use and Consumer Costs of Connected and Automated Vehicles, *http://www.nrel.gov/docs/fy17osti/67216.pdf* (2016)

Approach: Conceptual calculation flows

Establish scenarios of different powertrain and CAV feature adoption rates over time





Quantify potential efficiency and travel behavior impacts of CAV features in different driving situations

Calculate national-level roll up from aggregating driving situation impacts by the relative proportion of national VMT each represents

2015

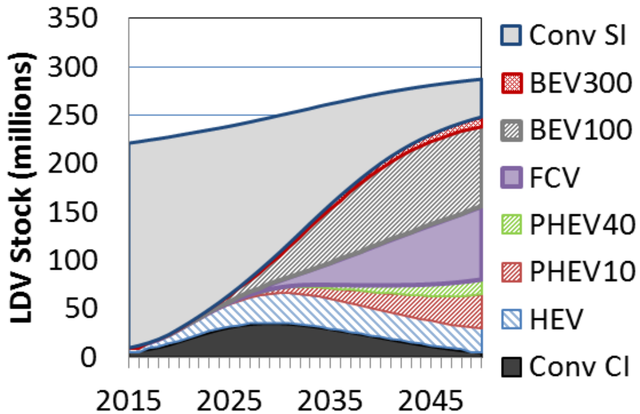
2040

Aggregate petroleum and GHG impacts of scenarios

Transfer regional analyses to estimate national evolution of VMT distributions over time

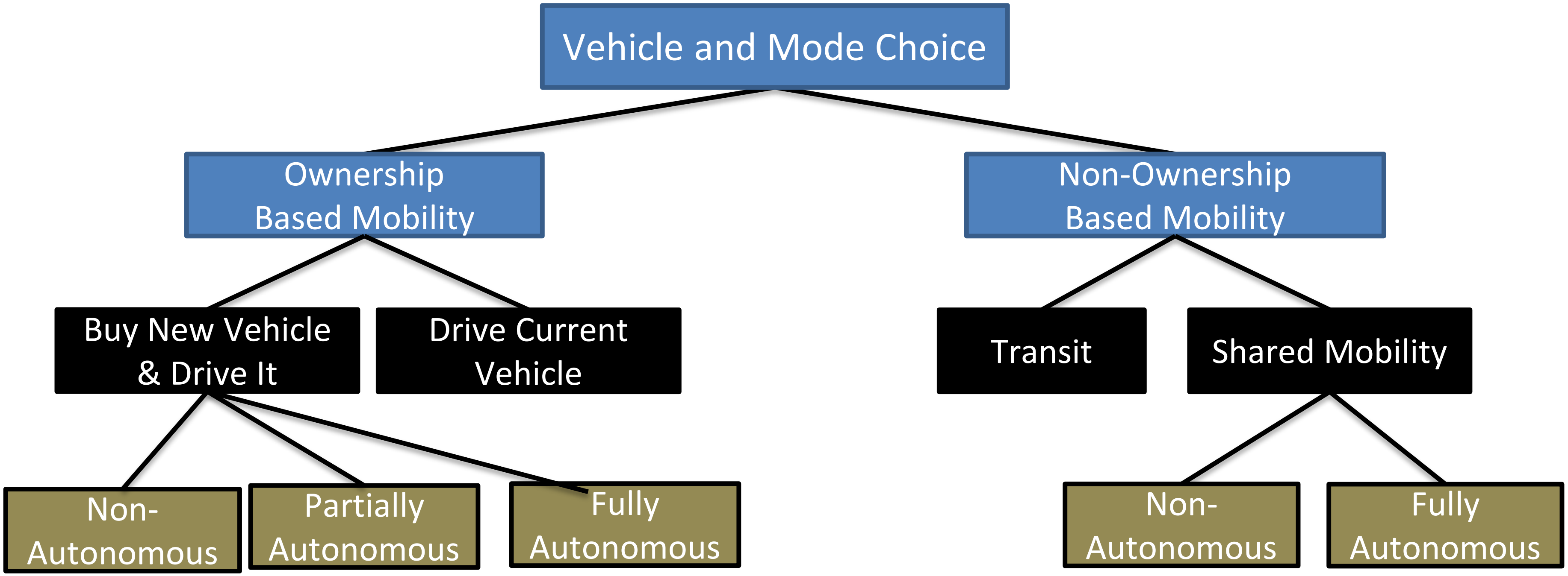
Approach: Implement value component methods to estimate CAV adoption rates

- Quantify utility to consumers within different market segments and resulting impacts on ownership and operation decisions
- Value components:
  - Stress
  - Time
  - Energy
  - Mobility
  - Productivity
- Integrate value components into ORNL's MA^{3}T model
- Revise MA^{3}T choice structure to include CAV
  - In addition to buy/no-buy a new LDV, add the options of buying a CAV and using AutoTaxis



Approach to Estimating CAVs Adoption: Adapt consumer choice model to include CAVs purchase decision

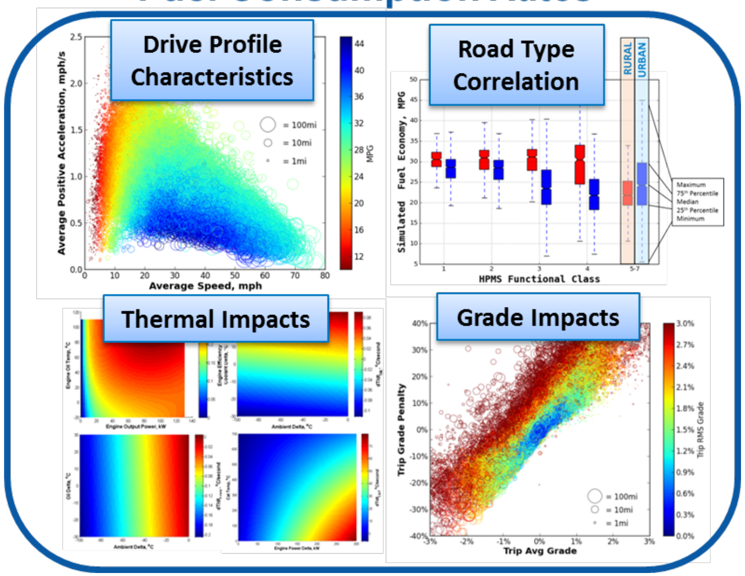
- Quantify utility to consumers within different market segments and resulting impacts on ownership and operation decisions
- Utility components: stress, energy, time, mobility, productivity
- Revise ORNL's MA^{3}T choice structure to include CAVs and other mode choices



Zhenhong Lin, Oak Ridge National Laboratory

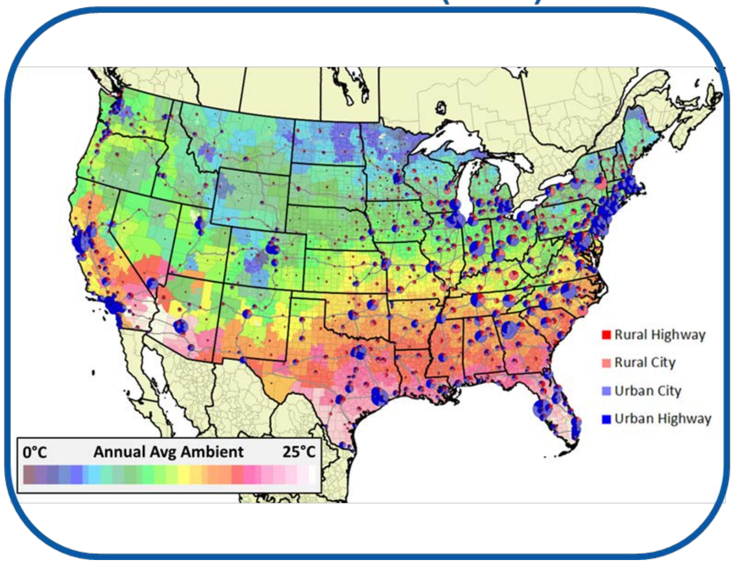
Approach: Aggregate energy/GHG impacts of CAV features nationally

Fuel Consumption *Rates*

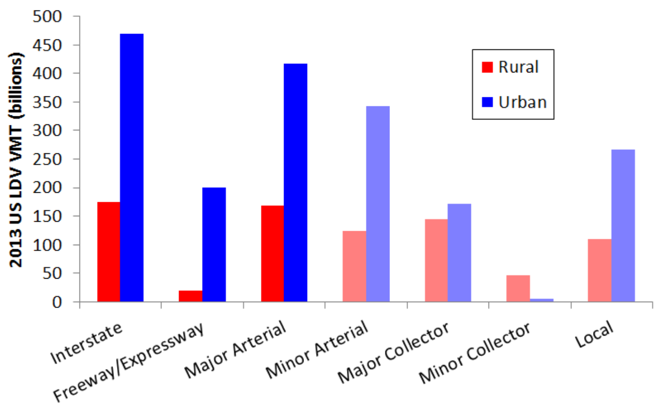


Quantify different CAV feature fuel economy impacts in different driving situations

Vehicle Miles Traveled (VMT) *Volumes*



Consider the relative proportion of national VMT represented by each driving situation



Calculate national total energy use and GHG emissions by summing VMT for the entire U.S. road network

Jeff Gonder, Yuche Chen, National Renewable Energy Laboratory

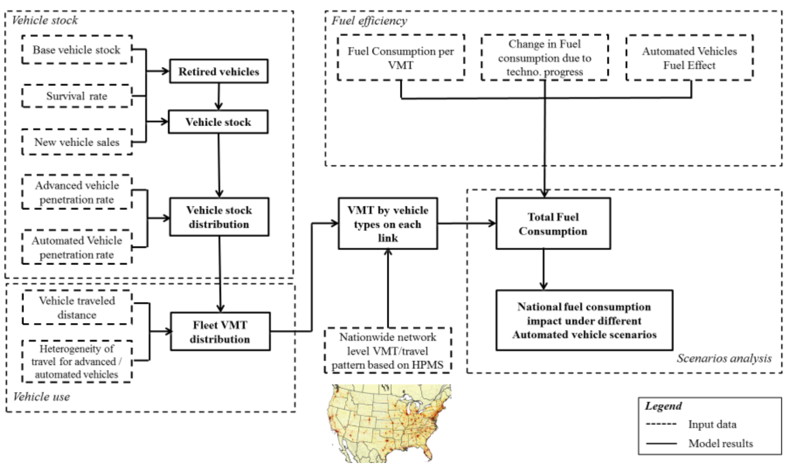
Accomplishment: Aggregate energy/GHG impacts of CAV features nationally

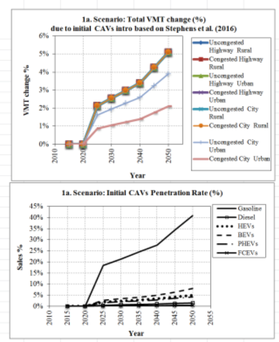
Established an analytical framework to assess energy/GHG impacts of CAV nationally

- ❑ Consider technology progress in non-CAVs and CAVs fleet
- ❑ Capture potential spatial and temporal energy impacts of CAVs
- ❑ Near-term focus on light-duty vehicle sector (but can be extended to heavy-duty trucks

Prepared preliminary assumption data for the national energy impact analysis based on

- ❑ Annual Energy Outlook 2017
- ❑ Results from Multi-Lab CAVs analysis report (Stephens, et al., 2016)
- ❑ Extensive literature review on CAVs features' mobility and vehicle-level energy impacts
- ❑ Educated guess / placeholder values





Focus	Scenario #	Base Example Concept	CAV Penetration Rate	CAV Powertrain Mix/Penetration Rate	Non-CAV Powertrain Mix/Penetration Rate	Anticipated VMT Effects	Anticipated Vehicle Efficiency Effects
Personal travel	1a	Cooperative ACC for light-duty passenger cars	Assume ramp to X% of all freeway driving over Y years	EIA base case	EIA base case	Possible small increase induced by reduced congestion	Small efficiency improvements from drive profile/traffic flow smoothing

Color coding map		
	Blue	Data directly from another source
	Red	Calculated values
	Green	Assumptions

Table 1. Percentage of VMT change

Year	Uncongested Highway Rural	Congested Highway Rural	Uncongested Highway Urban	Congested Highway Urban	Uncongested City Rural	Congested City Rural	Uncongested City Urban
2015	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2020	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2025	2.13%	2.13%	2.13%	2.13%	2.13%	2.13%	1.63%
2030	2.55%	2.55%	2.55%	2.55%	2.55%	2.55%	1.95%
2035	2.98%	2.98%	2.98%	2.98%	2.98%	2.98%	2.28%
2040	3.40%	3.40%	3.40%	3.40%	3.40%	3.40%	2.60%
2045	4.25%	4.25%	4.25%	4.25%	4.25%	4.25%	3.25%
2050	5.10%	5.10%	5.10%	5.10%	5.10%	5.10%	3.90%

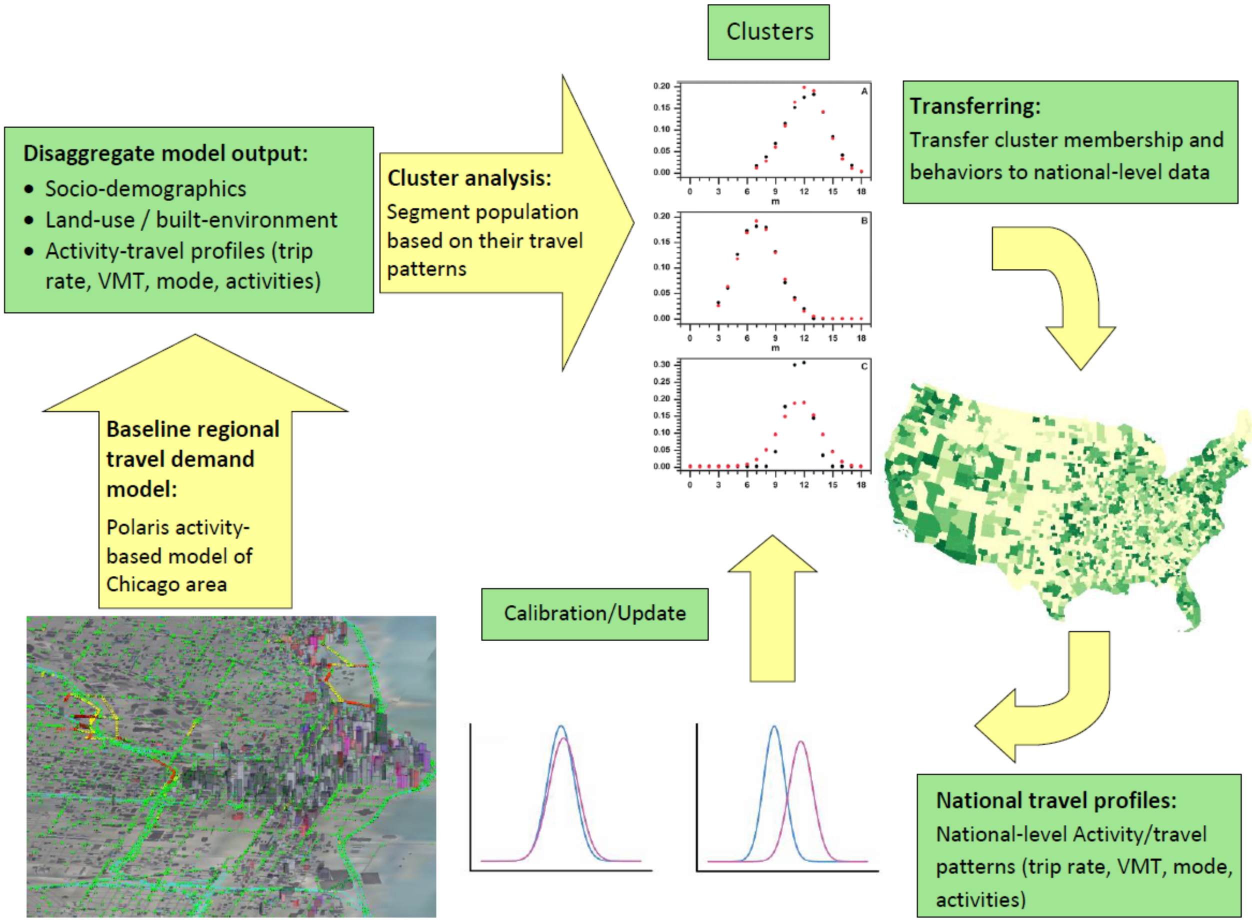
Table 2. CAV Powertrain Penetration Rate:Initial CAVs Technology Penetration %

Year	Gasoline	Diesel	HEVs	BEVs	PHEVs	FCEVs	Percentage of Partial CAVs in
2015	0%	0%	0%	0%	0%	0%	0%
2020	0%	0%	0%	0%	0%	0%	0%
2025	18.32%	0.33%	1.85%	2.66%	1.66%	0.18%	25%
2030	21.32%	0.75%	2.34%	3.37%	2.01%	0.21%	30%
2035	24.53%	0.89%	2.88%	4.05%	2.42%	0.23%	35%
2040	28%	1%	3%	5%	3%	0.27%	40%
2045	34%	1%	4%	6%	4%	0.33%	50%
2050	41%	2%	5%	8%	4%	0.42%	60%

Jeff Gonder, Yuche Chen, National Renewable Energy Laboratory

Approach: Use transferability modeling to expand detailed travel simulation results to the national level

- Transfer results from detailed transportation system simulations of CAVs in a metropolitan area to the rest of U.S.



Approach: Transferability permits use of rich datasets to map travel patterns

- Input data:
  - Disaggregate output from Polaris transportation system simulation
  - US Census American Community Survey
  - Census 2015 TIGER/Line geographic information system (GIS) data
  - National Household Travel Survey (NHTS) 2009

- Individual-level variables:
  - Age groups
  - Gender
  - Race/ethnicity
  - Marital status
  - Education level
  - Job category

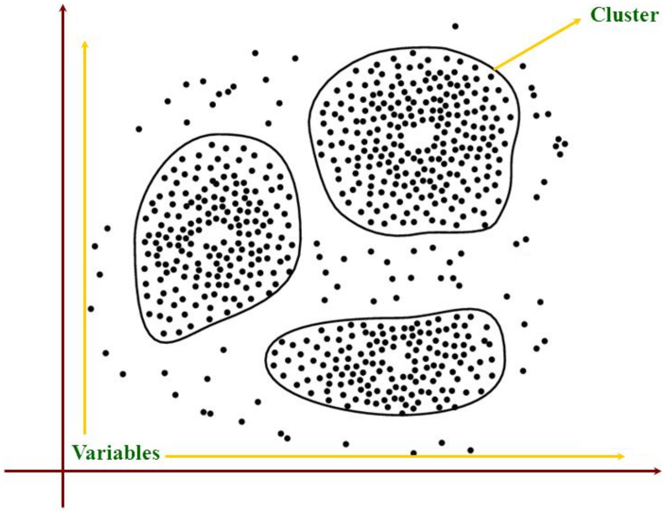
- Household-level variables
  - HH size
  - HH income
  - No. adults, workers, vehicles
  - HH members by race/ethnicity
  - HH members by educ. level
  - HH members by occupation type

Approach: Travel patterns can be transferred to households with similar characteristics

1. Take simulations results from the POLARIS model of the Chicago metropolitan area
   – Person-level and household-level demographic attributes
   – Detailed activity-travel patterns

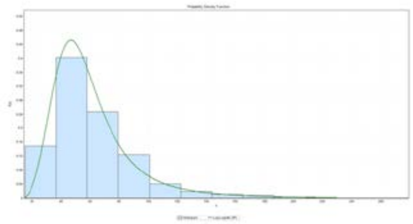
2. Derive transferable variables such as total trip rates and travel times from the simulation outputs

3. Cluster people into several homogeneous groups representing various types of lifestyles, utilizing rule-based Exhaustive Chi-squared Automatic Interaction Detector decision tree for each transferable variable



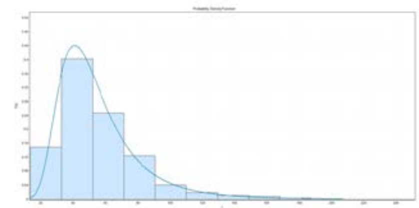
Approach: Travel patterns can be transferred to households with similar characteristics

4. Fit the best statistical distribution to each one of the final clusters to show the specific travel behaviors of cluster members

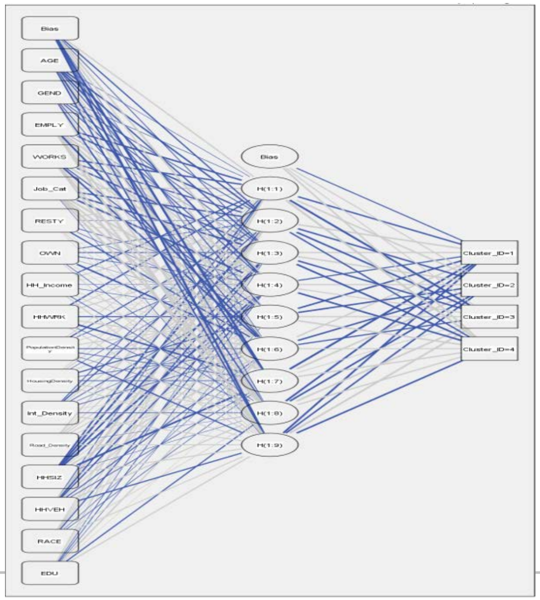


Observed travel distance distributions (Example: Group 16)

Transferred travel distance distributions (Example: Group 16)

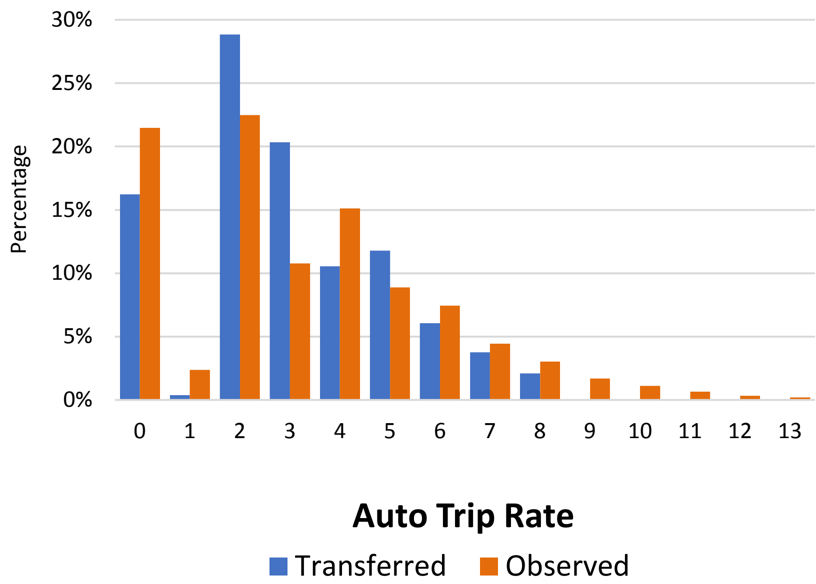


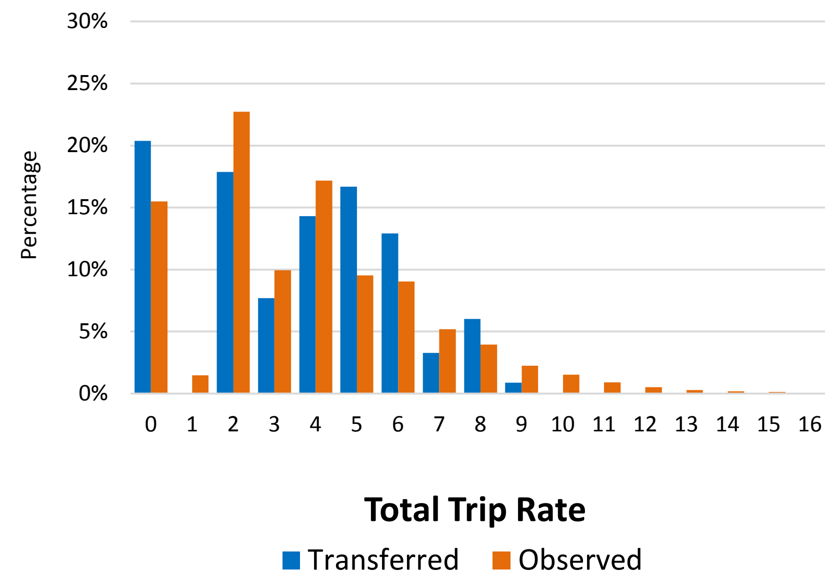
5. By using an artificial neural network model, transfer cluster membership and travel statistics to the national level to develop a baseline national platform to analyze CAVs scenarios



Accomplishment: Transferred and observed frequencies agree

For example: Cluster 2





- Good agreement
- Further validation in progress

Shabanpour, R., Mohammadian, A., Auld, J., Stephens, T. (2017) “Developing a Platform to Analyze Behavioral Impacts of Connected Automated Vehicles at the National Level,” TRB paper, No. 17-06283.

Accomplishment: Key questions/uncertainties identified

Light-duty passenger travel

- How will travel demand change with CAVs?
  – Induced demand, empty vehicle travel, ridesharing
- How will CAVs be adopted (what technologies, what level)?
  – User acceptance, costs
- How will vehicle fuel economy change with CAVs (not including vehicle resizing/redesign)?
- How vehicles will be resized under CAVs scenarios?
- How to expand local/regional studies to national level?
  – By vehicle type & roadway conditions
  – By household

Heavy-duty vehicles

- What is energy impact of truck platooning/automation?
  – Adoption levels, fraction of truck vehicle-miles-traveled in platoons

Response to Reviewer Comments

- This project is a new start

Collaborations

- Close collaboration with the related CAVs Pillar tasks (ANL, NREL, ORNL)
  - Defining scenarios and assumptions for case studies
  - Will take results from collaborators and roll up to national level
- Informal collaborations with wider research community through TRB subcommittee and Automated Vehicle Symposium, Universities, DOT Volpe Laboratory

Remaining Challenges and Barriers

- Further develop expansion aggregation methods and apply these to simulation results
  - Transferability of travel patterns
  - Mapping CAV efficiency to routes throughout U.S.
- Estimating potential adoption of CAVs technologies by different population segments
- Assessing CAVs impacts in other transportation sectors (heavy-duty vehicles)

Proposed Future Work

- Expand transferability modeling to additional travel characteristics
- Estimate potential adoption/utilization of CAVs by different user groups
- Analyze results of CAVs scenario simulations and roll up to national level
  - Connected vehicles in urban environment (traffic smoothing)
  - Connected vehicles on highways (CACC, platooning)
  - Automated vehicles in urban environment (driverless taxis, with/without ridesharing)

Summary

- The future of CAVs is very uncertain; key unknowns include impacts on
  - Travel demand
  - Vehicle use/ownership, CAVs adoption
  - Coevolution of vehicles with automation and connectivity
- Simulations and analyses of well-defined scenarios need to be synthesized into consistent, national-level assessments of potential impacts
- Important data gaps have been identified to help define scenarios and case studies to analyze next
- Synthesis approaches are being developed
  - Consumer value/adoption
  - Disaggregation by road type
  - Transfer of region-specific results to national scale
- Costs and values of CAV technologies to consumers are being used to assess potential adoption by different consumer segments
- These will connect projected outcomes to policy and technology drivers

Relevance

Approach

Accomplishments

Future work